Renewable and Sustainable Energy Reviews 14 (2010) 3041–3049

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

The situation of biofuels in Brazil: New generation technologies

Antonio Carlos Augusto da Costa [a,*], Nei Pereira Junior [b,1], Donato Alexandre Gomes Aranda [c,2]

[a] Laboratório de Bioprocessos, Departamento de Tecnologia de Processos Bioquímicos, Instituto de Química, Universidade do Estado do Rio de Janeiro, Brasil, R. S. Francisco Xavier 524, Pav. Haroldo Lisboa da Cunha, Room 427, Rio de Janeiro 20550-013, Brazil

[b] Laboratórios de Desenvolvimento de Bioprocessos, Departamento de Engenharia Bioquímica, Escola de Química, Universidade Federal do Rio de Janeiro, Brasil, Av. Horácio Macedo 2030, Bloco E, Brazil

[c] Laboratório de Tecnologias Verdes - Greentec, Departamento de Engenharia Química, Escola de Química, Universidade Federal do Rio de Janeiro, Brasil, Av. Horácio Macedo 2030, Bloco E, Brazil

ARTICLE INFO

Article history:
Received 19 April 2010
Accepted 20 July 2010

Keywords:
Biofuels
Ethanol
Biodiesel
Sustainable development
Future technologies

ABSTRACT

Biorefinery defines an industrial structure based on the use of biomasses for the production of a wide variety of molecules. Its purpose is to obtain high-cost products from low-cost feedstocks. The stronger candidates for this technology include residual and agro-industrial biomasses. This work includes a review on the state-of-the-art on the production of biofuels in Brazil, as well as the tendencies and present situation of this field in Brazil. These information bring important data for the evaluation on the potential use of biomasses for the production of biofuels, serving as a starting point for a prospective technology for the production of biofuels, based on the use of renewable sources.

Contents

* Corresponding author. Tel.: +55 21 25877631; fax: +55 21 25877227.
E-mail addresses: acosta@uerj.br, acosta@centroin.com.br (A.C.A. da Costa), nei@eq.ufrj.br (N.P. Junior), donato@eq.ufrj.br (D.A.G. Aranda).
[1] Tel.: +55 21 25627644; fax: +55 21 25627567.
[2] Fax: +55 21 25627657.

1364-0321/$ – see front matter
doi:10.1016/j.rser.2010.07.058

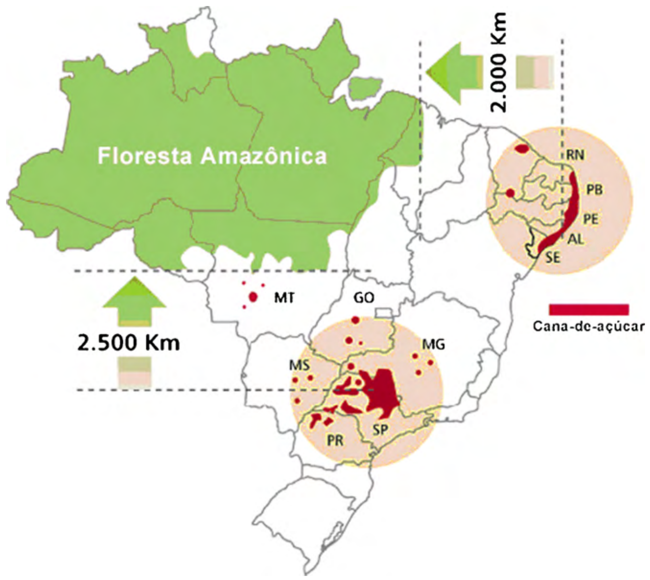


Fig. 1. Sugarcane production in Brazil.Source [3].

1. Feedstocks for the production of liquid biofuels

1.1. Ethanol

Brazil is the world's largest producer of sugarcane. In 1961, Brazil was responsible for 85% of the total sugarcane produced in the countries from MERCOSUL and has since increased to 97% because of Brazil's technological advances relative to the remaining countries. Brazil's share of world sugarcane production increased from 16% to 34% in 43 years. Internal production in the same period increased by 647%, and this increase was stimulated by internal policies directed to increase the consumption of alcohol as fuel [1]. Fig. 1 shows the main sugarcane producing regions in the country. Production of sugarcane reached 571.4 million tons in 2007/2008, and from this total, 68.5% of the production is concentrated in the southeastern region. In the region, production is mainly from São Paulo, which is responsible for 62% of the total production. The average productivity obtained was 74 tons/ha, except for São Paulo, which had the highest productivity level (equal to 83.5 tons/ha) [2].

Table 1
Productivity of oleaginous seeds in Brazil.

Culture	Source of oil	Harvest/year (months)	Productivity (kg/ha)	Oil content (%)
Cotton seed	Seed	3	3000	12
Peanut	Seed	3	1600	39
Babassu palm	Fruit	12	1600	62
Canola	Seed	3	1700	39
Palm	Fruit	12	25,000	20
Sesame	Seed	3–6	650	50
Sunflower	Seed	3	1500	41
Castor bean	Seed	3	1500	45
Castor bean (irrigated)	Seed	3	5000	45
Corn	Seed	3	3100	6
Pinhão manso	Seed	3–6	6500	38
Soybean	Seed	3	2300	20

Adapted from [1].

1.2. Biodiesel

Brazil, due to its huge territorial extension and climate conditions, is one of the primary countries for the use of biomass for feeding, chemical and energy purposes. Bahia State deserves special consideration due to its excellent conditions for production of oleaginous feedstocks used in the production of biodiesel. These feedstocks are mainly castor bean, soybean, palm, cotton and sunflower, which were recently introduced in experimental areas for energy production purposes. Table 1 represents the main cultures cultivated in Brazil, as well as the average yield estimates reported as amount of vegetable oil/area. Based on productivity data estimated for several cultures, it can be observed that pinhão manso (*Jatropha curcas*) presents outstanding productivity in comparison to other cultures.

Figs. 2 and 3 present the maps representing the localization of cultures of soy and oleaginous seeds in Brazil, respectively.

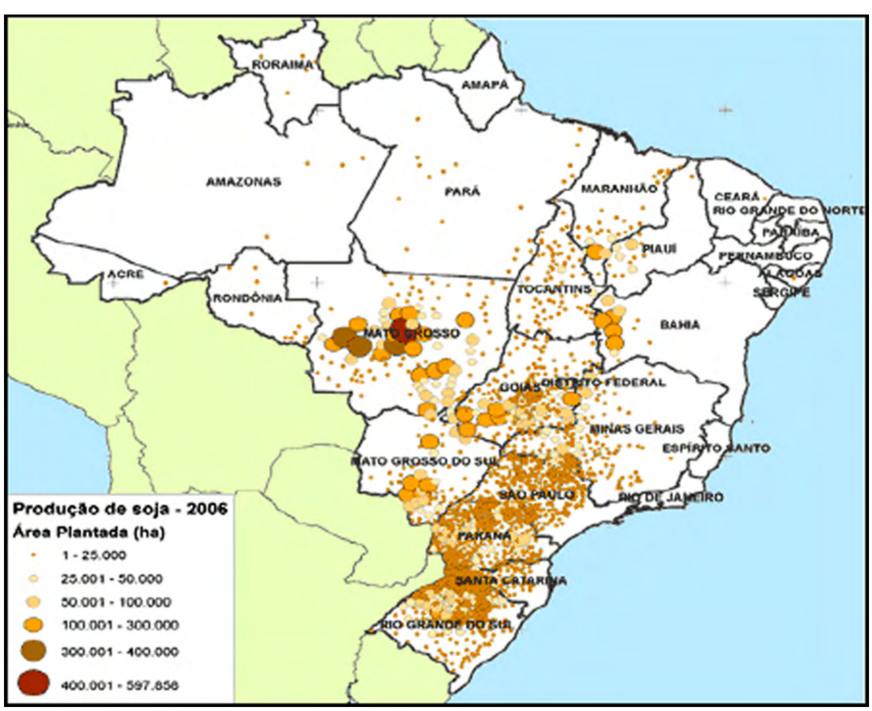


Fig. 2. Cultures of soy in Brazil.Source [1].

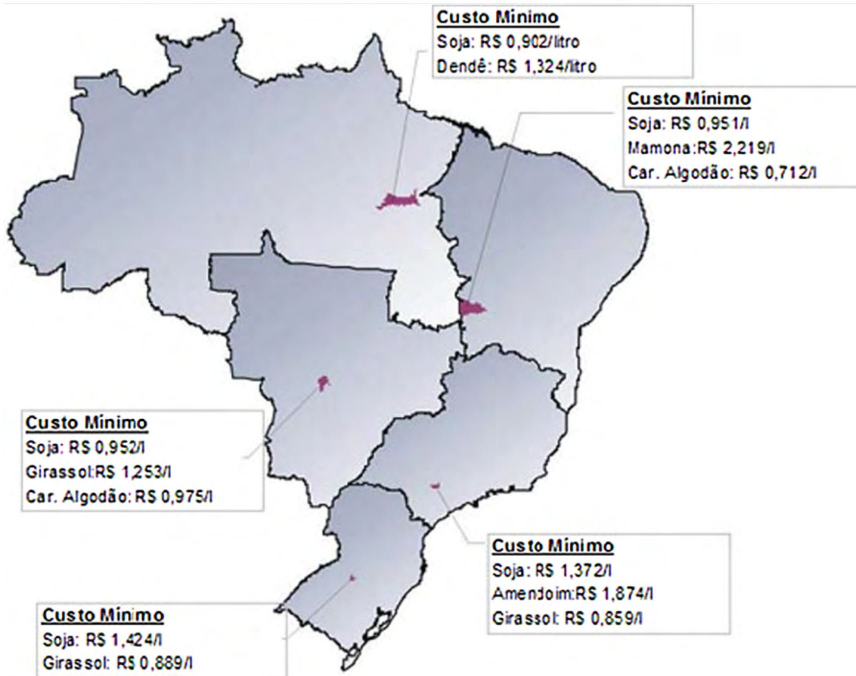


Fig. 3. Cultures of oleaginous seeds in Brazil.Source [1].

2. Energy matrix for transportation

The National Energy Balance constitutes the official document from the Mining and Energy Ministry, which is designated to register energy statistics. The internal offer of energy, distributed through sectors, is presented in Fig. 4.

2.1. Ethanol

In order to prevent price policies from Organization of Petroleum Exporters Countries (OPEC) the Brazilian Alcohol National Program (Proalcool) was established in 1975 with the main purpose of stimulating alcohol production for the internal and external market. During the Proalcool program, five distinct phases could be detected.

The first phase was characterized by a strong effort to increase the production of anhydrous alcohol, using molasses, in order to mix with gasoline fuel (1975–1979).

The second phase (1980–1986) was characterized by the second shock produced by the petroleum industry, where the price of the oil reached US$ 36/barrel. In 1980, importations reached 46%. Alcohol production reached, by the end of the period, 12 billion liters, 15% higher than the estimated goal established; during this stage, the proportion of alcohol-based cars increased from 0.46% in 1979 to 76.1% in 1986.

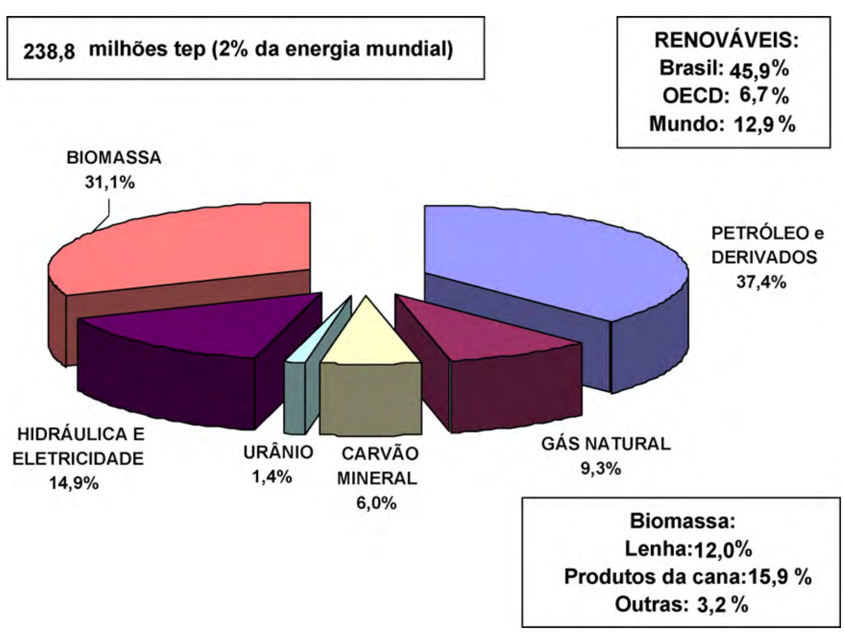


Fig. 4. Internal supply of energy in Brazil (2007).Source [4].

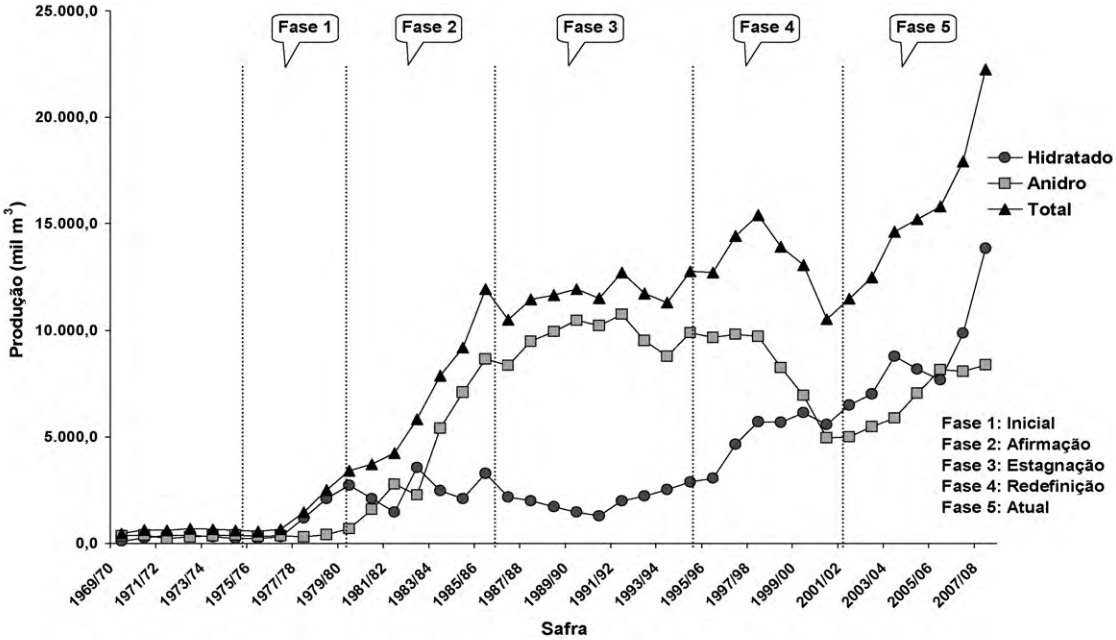


Fig. 5. Historic evolution of alcohol production in Brazil and its relation to the phases of Proalcool Program.Source [1].

The third phase, called the stagnation period, lasted from 1986 to 1995. In 1986, the world petroleum scenario changed, and petroleum prices decreased from US$ 40 to US$ 15/barrel. This stage was characterized by a reaction from petroleum industry, and it markedly jeopardized the development of alternative fuels.

By the end of 1995, the Federal Government reconsidered the Proalcool Program. This is the first step of the fourth phase of Proalcool, the redefinition phase that lasted until 2000. The Program still had two obstacles to face: the automobile industry markedly decreased production of alcohol-based cars, and due to international prices, the sugarcane industry decided to produce sugar instead of alcohol [5]. In 1998, the government agreed to increase the percent alcohol addition to gasoline, from 22% to 24%.

The fifth and present phase was affected by two shocks from the petroleum industry. The terrorist attacks against New York and Washington in September 2001 and the interruption of the Venezuelan production culminated with the importation of gasoline by the country. In 2004–2005, the world economic scenario regarding the price of petroleum also contributed to the implementation of the Program.

Fig. 5 shows the historic evolution of the total ethanol production.

Thirty years after the first phase of the Proalcool Program, Brazil has started a new expansion of sugarcane production with the purpose of offering the fuel at a large scale. The technology of flex-fuel cars markedly stimulated the internal market for alcohol as fuel. Introduced in Brazil in March 2003, the cars can use gasoline, alcohol or a mixture of both fuels. Today in Brazil, the flex-fuel option is offered across the automobile industry, and cars based on both fuels have, for the first time, surpassed the number of cars working on gasoline alone.

2.2. Biodiesel

The National Program for Biodiesel (PNPB) was created by the Brazilian Government in order to produce one billion liters of the fuel per year, starting from 2008. The program also intends to stimulate the exportation of the product, already used in the United Stated and in some European countries such as Germany and France.

PNPB is an Interministerial Program from the Federal Government with the purpose of implementing the production of biodiesel in Brazil, in a technically and economically sustainable way. Also, PNPB promotes social inclusion and regional localized development through the creation of new employment positions and financial income.

For almost half a century, Brazil's research on biodiesel pioneered initiatives for the use of this fuel, presenting the first patent on its production in 1980. In 2002, the attention on biodiesel has returned with the government introduction of this biofuel into the energy matrix and with the creation of a strong working group for the actual implementation of PNPB (Executive Interministerial Commission and Management Group) in 2003. Finally, in 2004, the implementation of PNPB, involving 14 Ministries and several research centers, began restructuring the available research networks.

In Brazil, the Biodiesel Law includes a paragraph about the addition of a minimum content of biodiesel addition to the conventional diesel oil (3%) beginning in July 2008, and it outlines the goal of reaching 5% in 2013. This includes the total volume of biodiesel produced by companies recognized by the government with the *Social Fuel Seal*. This is to be commercialized through public offers (auctions), organized by the ANP (National Agency for Petroleum, Natural Gas and Biofuels), and is to limit the volume of national demand for mineral diesel oil to 3%. This internal policy is markedly stimulating investment in the production of biodiesel, and several industrial plants are planned for construction soon, as observed in Fig. 6.

With a total volume of 660,000 m^3 of biodiesel negotiated in public offers in 2008, Brazil currently implemented the mixture B3 in July 2008 (3% biodiesel added to the mineral diesel), and B4 by July 2009.

3. Present status of biofuels in Brazil

3.1. Ethanol

The Proalcool Program was responsible for important transformations in Brazil in terms of its strategic position on energy, with a high potential to expand beyond the present limits. The high

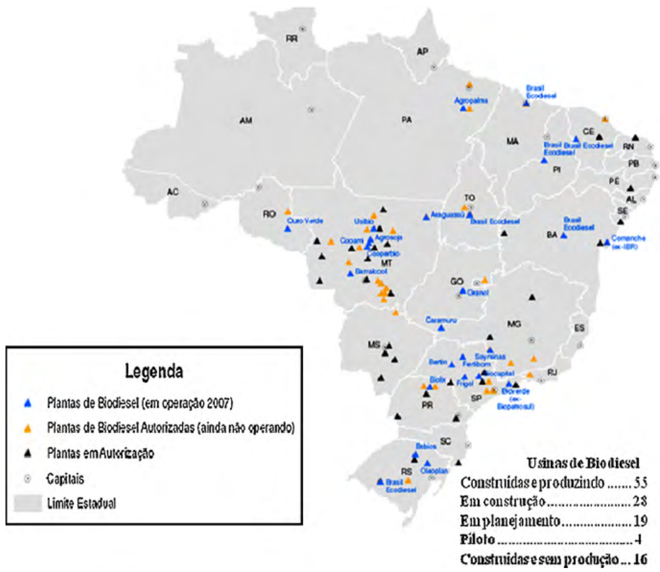


Fig. 6. Infrastructure for the production of biodiesel in 2007.Source [6].

availability of energy resources from mineral, hydric and biomass sources, along with the availability of advanced technologies, has contributed to worldwide recognition of Brazil's position among the top countries that will control the energy market in the near future. Such impacts can be encompassed in six classical topics: environmental, energy, economic, social, technological and strategic.

For Brazil, ethanol can supply more energy than necessary. The ratio of produced to consumed energy in Brazil is around 8.3, while in the United States it is 1.3 [7].

From the social point of view, the sugar–alcohol industry is presently one of the main suppliers of jobs in the Brazilian economy. It is responsible for one million positions, half with a focus on alcohol and the remaining half focused on the production of sugar. Sugarcane agro-industry proves to be capable of absorbing a remarkable portion of the rural jobs beyond the generation of additional positions and thus strongly contributes to a decrease in the rural-to-urban migration and helps prevent the uncontrolled growth of big cities. Beyond this, there has been development in the industry to produce cars that run on alcohol fuel. To work with alcohol, automobiles in several climate regions of the country required engineering to adapt regular vehicles (which use the Otto cycle) for ethanol. In addition, the effort of universities and research centers, both private and governmental, led to remarkable scientific and technological advances. Table 2 presents the distribution of Brazilian ethanol production in the different regions of Brazil.

3.2. Biodiesel

In 2008, 2 years after the implementation of the National Biofuels Program in Brazil, the country has 55 companies producing biodiesel and 65 companies involved in projects associated with the Program. This program includes 30,000 rural jobs. Biodiesel production is constantly increasing in Brazil, reaching 402.154,000 m^3/year (Table 3 and Fig. 7) in April 2008. This estimate positions Brazil close to the highest biodiesel producers in the European Union.

Table 3
Production of biodiesel B100, m^3/year.

Month	Year			
	2005	2006	2007	2008
January	–	1211	16,947	75,659
February	–	1287	16,740	75,901
March	8	2102	22,606	61,827
April	13	2147	18,773	63,729
May	26	2578	25,891	76,149
June	23	6490	26,977	100,811
July	7	3331	26,537	103,593
August	57	5102	43,665	–
September	2	6735	45,941	–
October	34	8581	53,523	–
November	281	16,025	54,755	–
December	285	14,531	49,800	–
Total	736	70,120	402,154	557,670

Source [8].

In 2007, the States of São Paulo and Mato Grosso lead in the production of biodiesel (Fig. 8). Mato Grosso State contains 14 plants authorized by ANP (National Agency for Petroleum, Natural Gas and Biofuels), and São Paulo State is the leader in productive capacity. With only nine biodiesel-producing plants, São Paulo State production reaches 576.2 million liters/year compared to 504.5 million liters/years for Mato Grosso State.

4. Perspectives for further developments

4.1. Ethanol

In the last harvest Brazil produced 22 billion liters of ethanol, 13% of which was for exportation. The remaining was to supply the internal market. According to Pereira [9], the estimated Brazilian demand for ethanol for 2013 will be around 31.7 billion liters. Of this, 16.4 billion liters are to be used in flex-fuel vehicles, 5.2 billion liters are to add to gasoline (26%), 7.0 billion liters are to supply the external market, 1.6 billion are to add to diesel oil (3%) and 0.4 billion are for the production of biodiesel. The remaining amount is designated for other purposes.

Short-term perspectives include an increase in agricultural areas for the production of ethanol, in order to satisfy the present demands for bioethanol. Because of the decreased supply of petroleum in the world market and the ratification of the Kyoto Protocol, the demand for ethanol is expected to increase both internally and by other countries. This fact brings opportunities for Brazil in terms of strategic participation in the international market. The Brazilian government will probably mediate negotiations in this field and

Table 2
Distribution of ethanol production in Brazil (billion liters).

Region	Year				
	2003	2004	2005	2006	2007
Total	14,469	14,647	16,039	17,764	22,556
North	39.39	47.53	47.51	75.88	47.66
Northeastern	1505	1675	1695	1572	1901
Southeastern	9786	9948	11,154	12,478	15,782
South	1.209	1.178	995,67	1.308	1.923
Center East	1.929	1.797	2.146	2.328	2.902

Source [1].

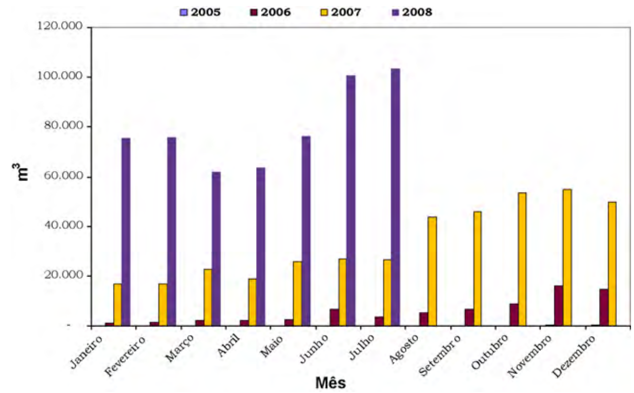


Fig. 7. National production of pure biodiesel (m^3) from 2005 to 2008.Source [1].

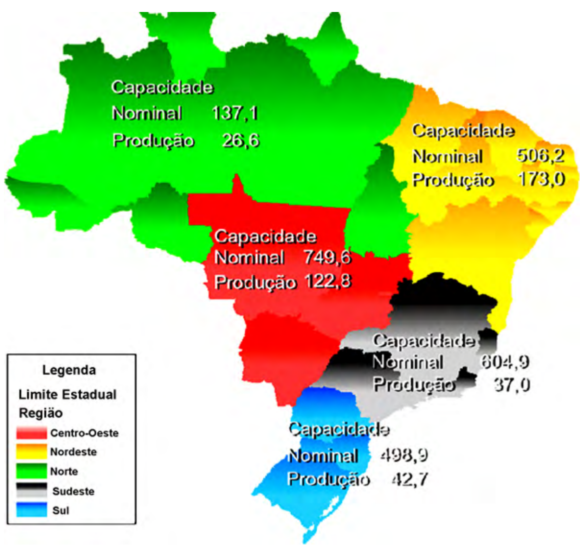


Fig. 8. Net biodiesel production capacity per region in 2007 (thousand m^3/year).Source [8].

assume a leadership position in terms of ethanol supply. In addition, Brazil will probably be included in another international market, the exportation of biofuel technology.

4.2. Biodiesel

The choice for the most suitable feedstock for the production of biodiesel seems to be one of the main problems in the field. In Brazil, 90% of biodiesel produced uses soy as the main feedstock, and the marked increase in the price of soybean in the international market was responsible for an increase of 44% in the average price of biodiesel. It is important to emphasize that the cost associated to the feedstocks corresponds to 80% of the total cost of biodiesel. Beyond this, the productivity obtained with the use of soy is not very favorable, producing around 700 l of biodiesel/ha, about one third of the total produced by other types of feedstocks.

Beyond these economic concerns, there are other points to be considered for the use of soy in the production of biodiesel, such as the impact on the price of food. Brazil still retains large areas available for agricultural purposes, and it is expected to produce 85 million tons of soy until 2011. Due to the importance of soy as a human and animal feed source, some researchers consider that using soy to produce biodiesel constitutes a mistake similar to producing ethanol based on corn.

With the regular use of soy, the focus of the Brazilian Biodiesel Program on social inclusion based on family agribusiness can be affected. The program's priority is to develop a technological base and to produce oleaginous seeds with high productivity, thus supporting the sustainable nature of the Program not only from the economical point of view, but also from the social point of view by supporting the family agribusiness.

5. A centered view of biofuels in Brazil

According to the Brazilian Minister of Foreign Affairs, Ambassador Celso Amorim, the global market for biofuels would represent a good opportunity for developing countries to increase their economic growth through production and use of new biofuels [10].

According to the Ambassador, it is not only a question of creating rural jobs but also the creation of additional positions in industrial plants and distilleries as well jobs in technical sectors associated with biofuel production (e.g., fertilizers, trucks, agricultural equipment, commercialization and transportation).

The positive and unquestionable impacts of the substitution of fossil fuels with environmentally friendly fuels will markedly affect the transportation sector — one sector most responsible for the emission of greenhouse gases. To have an idea of this impact, from 1970 to 2004 an increase of 120% was observed in the total amount of gases produced. Another point to be considered is that the use of biofuels, the mixture of ethanol with gasoline, and the substitution of fuel oil with bagasse has prevented the release of 675 million tons of carbon dioxide since the start of the Proalcool Program. Social inclusion, promoted through planning and implementation of public policies such as the National Program for Biodiesel, is another impact to be considered. The program *Green Seal*, promoted by the Brazilian government, includes differentiated taxes to companies that use feedstocks produced by small family farms from the poorest regions in the country. Thus, the use of biofuels in Brazil is based on the concept of sustainable development with a technical, economic, environmental and social focus. Biofuels constitute an opportunity for the government and private sector to work together, contributing to an improvement in the quality of life for a considerable portion of society.

6. How to be included in a competitive international market

Ambassador Antônio José Ferreira Simões brings us information about the Brazil's intent to position biofuels as a strategic product that can provide advantages for the country [10]. This leadership position can be reached, and some pre-requisites for Brazil's leadership are already in place: the issue of energy and natural resources, the discussion of biofuels as a strategic element for the country, environmental issues, population financial income and the controversial question around the supply of food for the population.

6.1. Energy and natural resources in Brazil

Production of energy and national strategy are closely related, and a central point of this relationship includes a country's access to natural resources. Scarce natural resources and the constant search for them is one of the key factors behind some political conflicts. Petroleum is a mineral resource needed for the operational establishment of military power and for civil productive applications in every country. The interruption of petroleum supply is presently a synonym of a collapse of a country. Due to this, the USA is searching for a way to control access to its resources as well as access to the routes by which this resource reaches consumers. Based on these simple and well-known assumptions, one can explain the military's influence on energy policies and the presence of the government in establishing strategic objectives for energy safety and supply as one of the basic standards of national security for a country.

6.2. Biofuels as a strategic element for a country

Worldwide the consumption of actual petroleum reserves is much higher than the discovery of new resources. According to some researchers, we have consumed close to half of all the oil resources in the planet; they estimate that in 10–30 years we will reach this point. According to the International Agency for Energy, the use of petroleum will increase 1.6% per year through 2030, reaching 120 million barrels/day. This represents an increase of 40% over the present use of around 86.1 million barrels/day [10].

The unquestionable leadership of Brazil in the field of biofuels represents a strategic advantage for the country; if well conceived and developed, it can contribute to the use of ethanol and biodiesel as important commodities and place the country into a favorable position as an energy supplier.

Fortunately, Brazil has 30 years of experience in this field and possesses a technological expertise higher than any other international player. It also has the qualified personnel, the political wish to implement technology in the field and — importantly — the agricultural areas available to produce enough sugarcane and oleaginous seeds for biodiesel without any need to build plantations in the Amazon Region or any other areas already directed to the production of food. Brazil is conscious about its position, and it is also conscious about the need for other international players also producing biofuels. Today, only 20 countries are producing energy for 200 countries. Brazil supports the democratic distribution of energy production, and a comfortable position would be 120 countries producing energy for those 200 countries.

It is important to emphasize that the Brazilian energy matrix is one of the "cleanest" in comparison to other countries; more than 45% of the total energy consumed in the country comes from renewable resources, in comparison to 15% from other developed countries. This brings a strategic advantage for the country in the present world scenario, where concerns about energy safety and environmental questions are a concern.

6.3. Relevant environmental questions

The production of biofuels in Brazil corroborates the environmental sustainable nature of this field. The last estimates made in Brazil (2007/2008) indicate that sugarcane production uses around 6.6 million ha, with a total of 82.5% located in the Center-South Region of the country. During this period, the production of fuel alcohol will consume 50.5% of the total sugarcane production, equivalent to 20 billion liters (an increase equal to 14.5% over the 2006/2007 period). Even based on this production, sugarcane uses only 10% of the total cultivated land in Brazil, and according to the Ministry of Agriculture, Husbandry and Supply, it is still possible to incorporate 100 million ha into the 62 million ha presently occupied for agricultural purposes. Thus, based on the continental size of the country, there is no need to use virgin forest areas to supply the present and future demand for alcohol.

The expansion in agricultural land in Brazil is present in São Paulo State, confirming that the use of the Amazon Forest for this purpose is absolutely incorrect, based both on land occupation and on climate conditions. The low fertility of the soil and the rain conditions in the Amazon area are not favorable for the cultivation of sugarcane. Sugarcane culture needs dry weather to form sucrose, and in regions such as the Amazon area, there is an abnormal absorption of water from the soil that prevents the formation of sugar.

In fact, the increase in the production of sugarcane and ethanol is based on huge investments made in universities and research centers that contribute to an improvement in the techniques used to increase productivity. Thus, smaller areas are producing the same amount of sugarcane and are preventing the need for additional land cultivation.

The focus of these research investments includes the development of new technologies for the hydrolysis of sugarcane bagasse and straw, with a much higher efficiency of production. Another relevant point is related to the excellent energy balance observed in the production of alcohol from sugarcane, as previously discussed.

6.4. Income, biofuels and food supply

The worldwide desire for biofuels has stimulated discussions about the competition between the use of land for the production of energy and food. This discussion is not new in Brazil. In 1970 when the Proalcool Program was established, several critics said that the increase in sugarcane production would destroy the environment and jeopardize the production of food in the country. After 30 years, we have observed that the production of sugarcane markedly increased, contributing to an economical and social development of several regions, particularly the Center-South Region of Brazil. In the same period Brazil has become an important producer and exporter of food (seeds, meat, sugar, etc.). Several specialists, such as Amartya Sen (Economy Nobel Prize in 1998), believe that the lack of food comes mainly from financial difficulties due to unemployment and low salaries. Some critics of the expansion of ethanol production in Brazil are frequently based on conditions of other countries, without a deep knowledge of the Brazilian reality.

A good example to illustrate this question is the production of ethanol from corn, as practiced in USA, which is stimulating high prices of this crop in the international market. However, trying to construct a simple analogy between corn and sugarcane products will lead to huge mistakes due to the peculiarities of each case. In the last 25 years, the expansion of sugarcane culture has not been dependent on irrigation. These agricultural areas are far beyond the Amazon Forest, the Atlantic Forest and the Pantanal Region. These plantations of sugarcane have not occurred in any forest area or any protected biome in the country. To compare, Brazil has 62 million ha of cultivated area today, and preserved areas in the country include 465 million ha. Comparatively, the area used for sugarcane production (for ethanol) is around 3.3 million ha (0.4% of the total size of Brazil). In order to produce the expected 36 billion liters of ethanol projected for 2012, this area must be increased to 0.7% of the total Brazilian land area.

It can therefore be concluded that Brazil, due to its continental area and huge availability of agricultural land, can produce food and ethanol while preserving its forests and native areas. Also, this renewable fuel markedly contributes to a decrease in CO_2 emissions.

Another consideration is that the production of biofuels in Brazil has increased in the same proportion as the consumption of food. As previously stated, the key factor that controls food supply is the financial income of the population rather than the production of Biofuels. If we consider that biofuel production contributes to an increase in the income of less-favored social classes, its production can be considered as an element responsible for a decrease in hunger and poverty.

According to the Brazilian Institute of Geography and Statistics, during 1976/1977 the cultivated area for seeds in Brazil was 37.3 million ha, and production was 46.9 million tons. The area designated for the cultivation of sugarcane was 2.1 million ha, with a total production of 100 million tons. More recently, in the period of 2000/2001, the production of grains and seeds reached 100.2 million tons from an area of 37.8 million ha. It can be easily concluded that the production practically doubled with an increase of only 500,000 ha of cultivated area compared to 1976/1977.

The same comparison can be made for sugarcane production. Its production reached 344 million tons for a cultivated area equal to 4.9 million ha. Such statistics demonstrate that, in this period, the

technological improvement in sugarcane production (from new plant varieties and soil types) contributed to an extensive increase in the production and a higher productivity. Simultaneously the production of food was also increased. The average yield of sugarcane for ethanol production increased from 2000 to 6000 l/ha.

These data support the idea that it is possible to increase Brazilian production of alcohol rapidly in order to meet the internal and external demand without any competition with the production of food. For example, in 160,000 ha of sugarcane, 1 billion liters of alcohol can be produced. The fact that the increased area used for sugarcane production is basically on pasture areas in the Center-South of the country also did not compete with the husbandry production in Brazil. In 2006, the area used for animal production in São Paulo State decreased 2.56%, the largest part of this decrease due to the substitution for sugarcane production. According to Agricultural Secretary of São Paulo State, the state lost around 4.8% of its total pasture areas for sugarcane production in the period 2000/2006. These facts did not mean, however, a decrease in the sheep. On the contrary, it increased by 5.6%, supporting the idea that the production of ethanol from sugarcane and the production of protein for human feed are not competitive sectors.

7. Sustainable bioethanol production and the reduction of greenhouse gases

The link between the emission of gases contributing to the greenhouse effect and the technological development of alternative fuels is discussed by Szwarc [10], a review that brilliantly denies any parallel relations between biofuels production and production of food.

Global warming results from the intensification of the greenhouse effect, a natural process responsible for the thermal equilibrium of the planet. Although the greenhouse effect keeps the average temperature on the surface of the Earth around 15 °C, its intensification can alter climate patterns, which have been relatively constant for centuries.

The primary cause of this intensification is the increase in the concentration of gases contributing to the greenhouse effect. Present data indicate that the average temperature on Earth has already increased 0.6 °C; this value could be as much as ten times higher by the end of this century. Even if a less dramatic scenario is presented, a 2 °C increase in the average temperature will have a significant impact on life around the planet. This increase may seem to be irrelevant, but it is enough to change wind and oceanic patterns as well as the global transport of thermal energy.

The main gases contributing to the greenhouse effect are carbon dioxide, methane and nitrous oxide. Other gases, such as hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride are present, but they are of minor importance due to their small concentration in the atmosphere. As a whole, the emission of these gases increased around 70% between 1970 and 2004 and reached 26.9 billion tons in 2004. For carbon dioxide, this increase was 80% during this period and was equivalent to 77% of the total gas emissions.

Beyond the greenhouse effect, other polluting agents such as carbon monoxide, volatile organic compounds and nitrogen oxides also contribute to global warming. The monoxide is gradually oxidized to dioxide, and the volatile organics and nitrogen oxides can take part in the formation of ozone, another greenhouse gas.

Although this huge growth in the emission of gases can be attributed to several sources, the sector that markedly contributes to the growth is the generation of energy. Energy-related emissions increased around 145% between 1970 and 2004. A remarkable increase was also observed in transportation, with emissions increasing around 120% during the same period. Comparatively, the increase from the industrial sectors was substantially smaller (around 60%).

Recent expectations of growth for the world economy are around 4% through 2030, including an increase in demand for petroleum from 83 million barrels/day (2006) to 118 million barrels/day.

On a related note, it is expected that in 2010 the number of vehicles will be approximately one billion cars, contributing to an increase in the emission of greenhouse gases. For this expected demand, it is mandatory to have alternative fuels, and the main strategies currently under discussion to reduce greenhouse gases include the following:

- decreasing the use of petroleum based compounds, through policy and actions that promote a rational use of this resource;
- increasing the energy efficiency of automotive vehicles;
- substituting petroleum derivatives for biofuels such as ethanol and biodiesel;
- intensifying the use of public transportation; and,
- intensifying development of innovative technologies, such as hydrogen in combustible cells.

The main factors that position Brazil as a viable player in the mitigation of the greenhouse effect are the following:

- production of sugarcane, a renewable feedstock, at a fast growth rate with the high potential to fix carbon dioxide;
- efficient production of energy, consuming just 0.12 kJ of the fossil energy for each 1.0 kJ of ethanol produces (this corresponds to 1 unit of fossil energy used in the generation of 8.3 units of renewable energy);
- near-neutrality in the carbon balance. During the growth cycle of sugarcane the amount of carbon dioxide fixed during photosynthesis is equivalent to the amount generated in the production/use of ethanol. Simple substitution of fossil fuels with ethanol can prevent the emission of greenhouse gas;
  - Carbon removed from the soil in the form of natural gas and petroleum derivatives, increases the stock of carbon in the air when released;
- emission of carbon dioxide through the combustion of ethanol is much smaller than through the combustion of fossil fuels. A gasoline-based vehicle releases 2.2 kg carbon dioxide/l, while an ethanol-based vehicle releases 1.3 kg carbon dioxide/l. The excess released by alcohol-based cars is compensated by the growth cycle of the sugarcane.
- large-scale production, competitive from the economic point of view.

The two types of ethanol normally used as fuel are hydrated and anhydrous. The hydrated alcohol contains 95% ethanol and the anhydrous contains 99.5% alcohol. Their applications include the following:

- Mixing with gasoline up to 10% in gasoline-based vehicles. For higher additions of ethanol (20–25%), as practiced in Brazil, vehicles were adapted and recalibrated to fit the mixture.
- In Brazil, where 5.5 million vehicles were produced to use ethanol only, the reduction in the emission is remarkable;
- can be exclusively used as an additive in diesel motors, after modifications;

8. Ethanol, international protectionism and concluding remarks

Despite its well-recognized environmental advantages and the growing number of countries using the alternative fuel, ethanol still faces some discrimination in several world markets and is subjected to huge importation taxes (as presently practiced by the USA, European Union, and Japan).

This protectionism, aimed at protecting local farmers, is not in accordance with the present demand for viable, reduced-cost fuel alternatives for mitigation of the greenhouse effect. This behavior also contributes to an intensive use of petroleum derivatives. In this context, all initiatives directed to reduce or eliminate these barriers are welcome. An editorial in the Financial Times in June 2007 critically evaluates this protectionist behavior, clearly stating that the greatest barrier for broad use of bioethanol in the USA is the North American ethanol industry itself. The editorial ends by suggesting that the European Union should follow the leadership of Sweden by eliminating importation taxes now, before it is too late.

Acknowledgements

The authors are thankful for the permanent support from Petrobras, CNPq, CAPES, FINEP, FAPERJ, Aracruz Celulose and Oxiteno. The authors also thank the Brazilian Ministry for Foreign Affairs, through its various collaborators, where certain part of the present statistical information were obtained.

References

[1] MAPA, Ministério da Agricultura, Pecuária E Abastecimento. Balanço Nacional da Cana-de-açúcar e Agroenergia: 2010; 2008, Brasília DF. Available at www.agricultura.gov.br [accessed in March 2010].
[2] CONAB. Perfil do setor de açúcar e álcool no Brasil; 2010, Brasília DF. Available at www.conab.gov.br [accessed in March 2010].
[3] UNICA; 2010. Available at www.unica.com.br [accessed in March 2010].
[4] MME, Ministério das Minas e Energia. Balanço Energético Nacional; 2010, Available at www.mme.gov.br [accessed in March 2010].
[5] Karan D. PROÁLCOOL: Cenas do século 20 - TV Cultura, São Paulo, 22 set; 1998, Disponível em: http://www.tvcultura.com.br/aloescola [acesso em: 10 fev. 2006].
[6] BIODIESEL. MAPA interativo do Portal Biodieselbr.com. Available at www.biodieselbr.com [accessed in March 2010].
[7] Urquiaga S, Alves BJR, Boodey RM. Produção de biocombustíveis: a questão do balanço energético. Revista de política agrícola Brasília 2005;1:42–5.
[8] ANP. Available at www.anp.gov.br [in March 2010].
[9] Pereira RE. Avaliação do Potencial Nacional de Geração de Resíduos Agrícolas para a Produção de Etanol. M.Sc. Dissertation. Programa de Pós-graduação em Tecnologia de Processos Químicos e Bioquímicos da EQ/UFRJ; 2006.
[10] MRE – MINISTÉRIO DAS RELAÇÕES EXTERIORES; 2010. Available at www.dc.mre.gov.br/imagens-e-textos/temas-brasileiros-1/portugues/teste-com-imagem [accessed in March 2010].